Faculty of Technology, Design & Environment

Assessment cover

STUDENTS, PLEASE COPY THIS PAGE AND USE AS THE COVER PAGE FOR YOUR SUBMISSION

Module No:	ENGR7025	Module title:	Electric Vehicles

Assessment title:	Assignment 1 Mini Project: DC-AC inverter and Regenerative Breaking

Due date and time:	10/03/23

Estimated total time to be spent on assignment:	30 hours per student

LEARNING OUTCOMES

On successful completion of this module, students will be able to achieve the module following learning outcomes (LOs): *LO numbers and text copied and pasted from the module descriptor*
1) Appraise different electric vehicles architectures, evaluate and compare their performance.
2) Evaluate different types of electric machines for vehicle propulsion to recommend choices and assess associated energy recovery systems.
3) Analyse and assess performance of a range of energy storage systems, including associated safety and battery management systems.
4) Consider different controller and inverter types and evaluate their operation and suitability for automotive applications.
5) Assess different electronic sub-systems such as on-board communication and shutdown system required for safe operation of an electric vehicle.
6) Assess electrical energy provision, energy sources and electrical grid mix composition. Quantify different options using whole lifecycle assessment.

Engineering Council AHEP4 LOs assessed (from S1 2022-23) *LOs copied and pasted from the AHEP4 matrix*	
M1	Apply a comprehensive knowledge of mathematics, statistics, natural science and engineering principles to the solution of complex problems. Much of the knowledge will be at the forefront of the particular subject of study and informed by a critical awareness of new developments and the wider context of engineering
M2	Formulate and analyse complex problems to reach substantiated conclusions. This will involve evaluating available data using first principles of mathematics, statistics, natural science and engineering principles, and using engineering judgment to work with information that may be uncertain or incomplete, discussing the limitations of the techniques employed
M3	Select and apply appropriate computational and analytical techniques to model complex problems, discussing the limitations of the techniques employed
M4	Select and critically evaluate technical literature and other sources of information to solve complex problems
M5	Design solutions for complex problems that evidence some originality and meet a combination of societal, user, business and customer needs as appropriate. This will involve consideration of applicable health & safety, diversity, inclusion, cultural, societal, environmental and commercial matters, codes of practice and industry standards
M7	Evaluate the environmental and societal impact of solutions to complex problems (to include the entire life-cycle of a product or process) and minimise adverse impacts

Statement of Compliance ***(please tick to sign)***

☑ I declare that the work submitted is my own and that the work I submit is fully in accordance with the University regulations regarding assessments *(www.brookes.ac.uk/uniregulations/current)*

School of Engineering, Computing & Mathematics

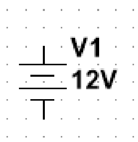
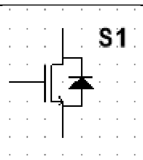
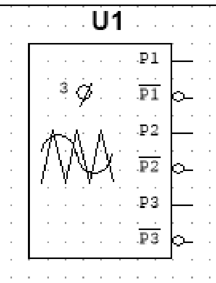
Introduction

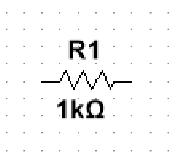
In recent years, the development of electric vehicles has become increasingly popular considering the advantages they offer in comparison to traditional IC engine vehicles. However, due to their limited range and longer charging duration, EVs have not yet attained commercial success. Batteries are the main source of energy in EVs, but due to their restricted size and weight the amount of energy stored is less (Bhurse & Bhole, 2018). Regenerative braking is a method which enables recover some energy and improves the driving range. EVs are propelled by AC motors and require AC supply for their functioning. However, the available power in batteries is DC, it is, therefore, necessary to convert DC into AC to operate the motor. This is achieved using an Inverter.

In the following parts of coursework, the operation and working of the Inverter and the regenerative circuit have been discussed in detail.

Part A- DC-AC Inverter

An inverter is a power electronic device which is used for converting DC power into AC power of a required voltage and frequency.

Component	Symbol	Definition	Function
DC Source		The term DC source refers to an electrical source which can provide constant current and voltage.	The DC source represents a battery in the circuit which is used to source constant voltage (0-200V)
Transistor Diode		A transistor diode is a semiconductor device whose function is to switch and amplify signals while allowing the current to flow in only one direction.	In the inverter circuit, the transistor diode is used as switch to control the flow of current.
Sinusoidal PWM		SPWM is a type of “carrier-based” pulse width modulation technique which uses predefined reference signals to generate desired output signals of a sine wave.	The SPWM is used to generate a three-phase sinusoidal PWM signal required to drive the inverter circuit which converts the DC supply into AC supply.

Resistor		Resistor is an electrical component used to limit the flow of current in the circuit.	In the inverter circuit, the resistor is used as a Load.

Circuit Design and Operation

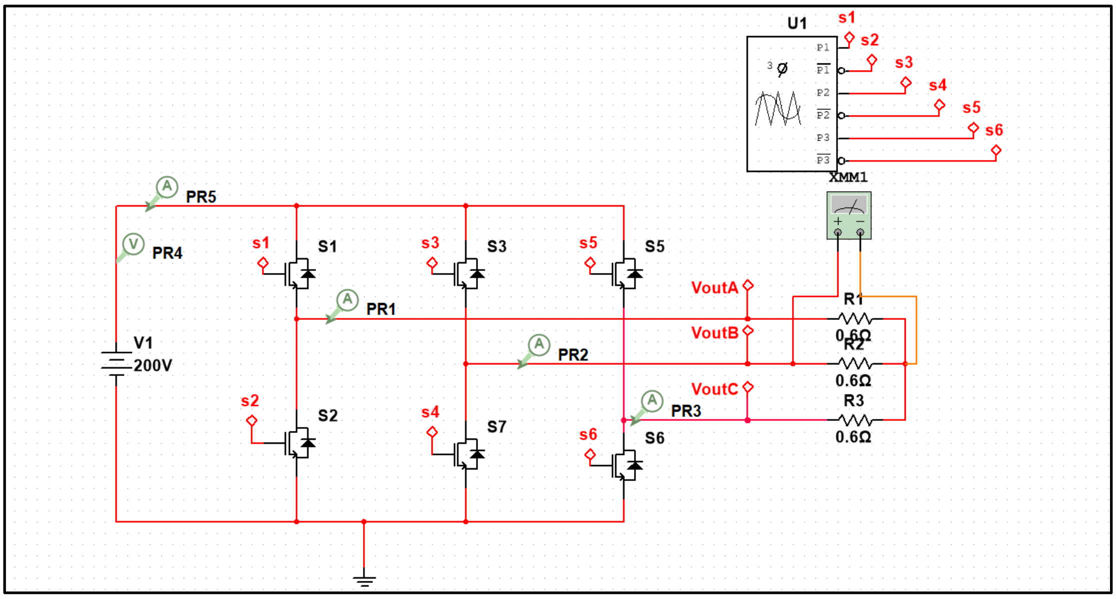


Figure 1 DC-AC Inverter Circuit

Figure 1 shows the circuit diagram of a three-phase Inverter circuit. During the operation, the power from the battery flows through the inverter bridge consisting 6 transistor diodes being used as switches and are operated in sequence to perform rapid switching functions to generate an output AC waveform. They also prevent the current from returning to the source. The opening and closing of these switches are controlled by the SPWM controller. The controller can open and close switches in pairs multiple times per cycle to control the flow of electricity by controlling the direction and duration of the flow to produce a controlled pulsating output. This way the current is made to flow in alternating directions and AC supply is generated.

The controller can change the amount of time the switches are open to vary the frequency and wavelength. Each pair of switches are operated at different times so we get 3 phase having 120° phase shift.

Analysis and Results

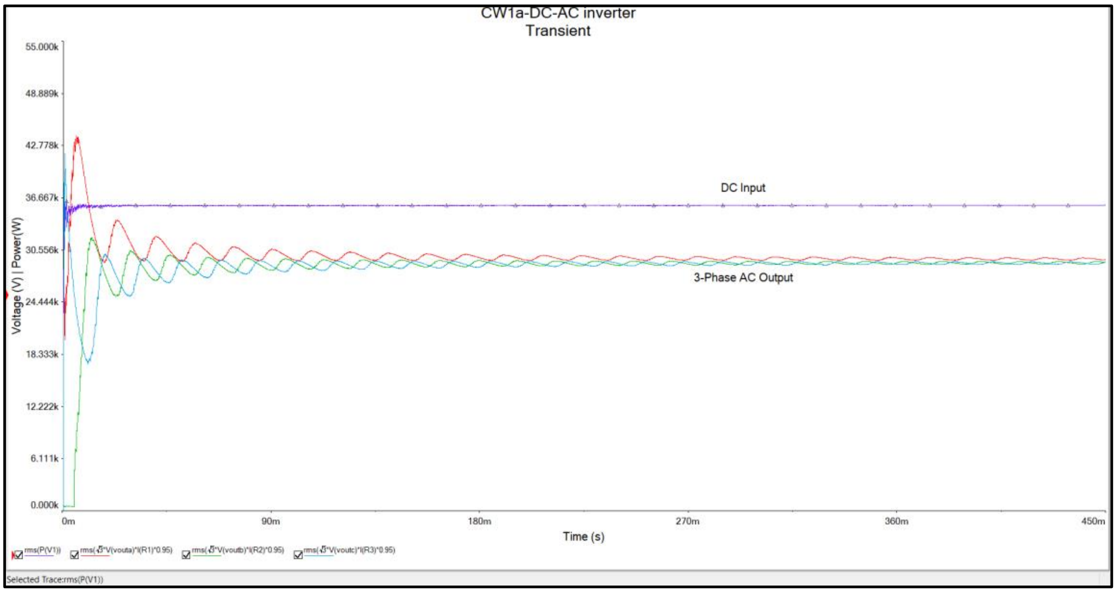


Figure 2 Input and Output Supply waveform

To estimate the system's average efficiency, the input and output power RMS was calculated for varying voltages from 0-200V in steps of 10V.

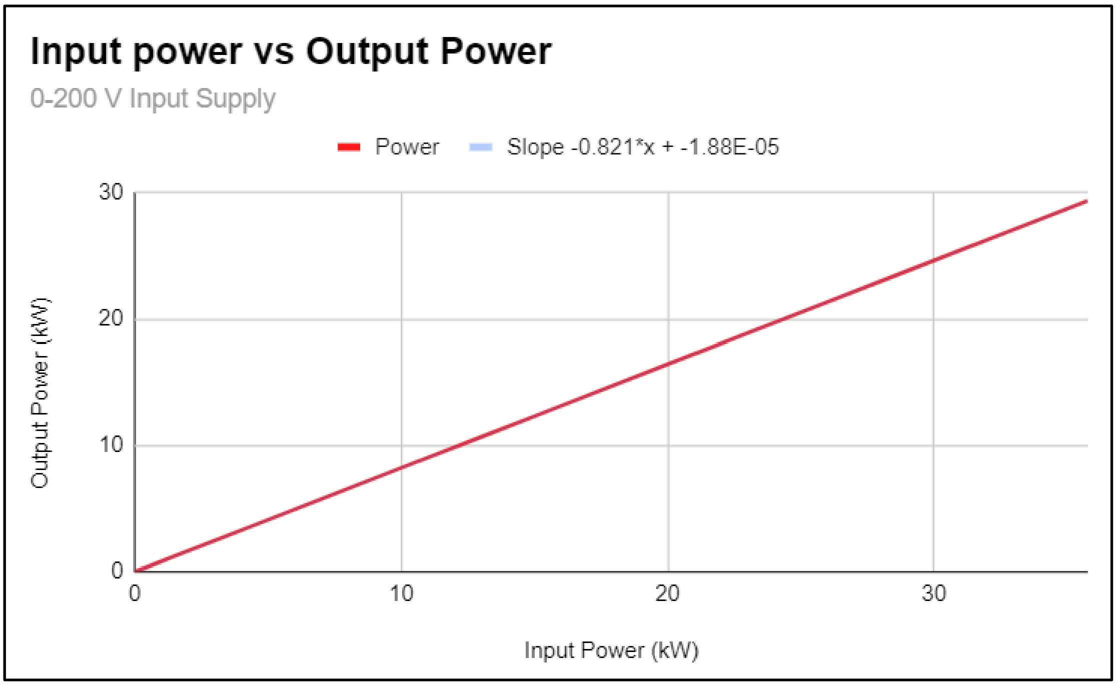


Figure 3 Power comparison graph for a Three-phase Inverter circuit

The effective output power is calculated using the following expression:-

$$P_{out} = rms(\sqrt{3} * V_{out} * I_{out} * Cos\Phi)$$

Where,

$V_{out} = Output\ Voltage$
$I_{out} = Current\ through\ Resistor$

$Cos\Phi$ = Power factor = phase angle between Phase Voltage and Phase current

To meet the ideal power factor of high-voltage power supplies for industrial applications, a power factor of 0.95 was used.(Fan, et al., 2020) The efficiency of an inverter circuit depends on multiple factors including input and output voltages, power factor, efficiency of the sub-components etc. The graph for output power to input power was observed to be linear, indicating a constant power efficiency regardless of the input voltage.

The overall power efficiency of the designed inverter system was 82.09%.

Part B- Regenerative Braking

Regenerative Braking is a braking technique employed in electric and hybrid vehicles where the motor acts as a generator and produces electrical energy by converting the mechanical power available from the kinetic energy during deceleration.

Circuit design and Operation

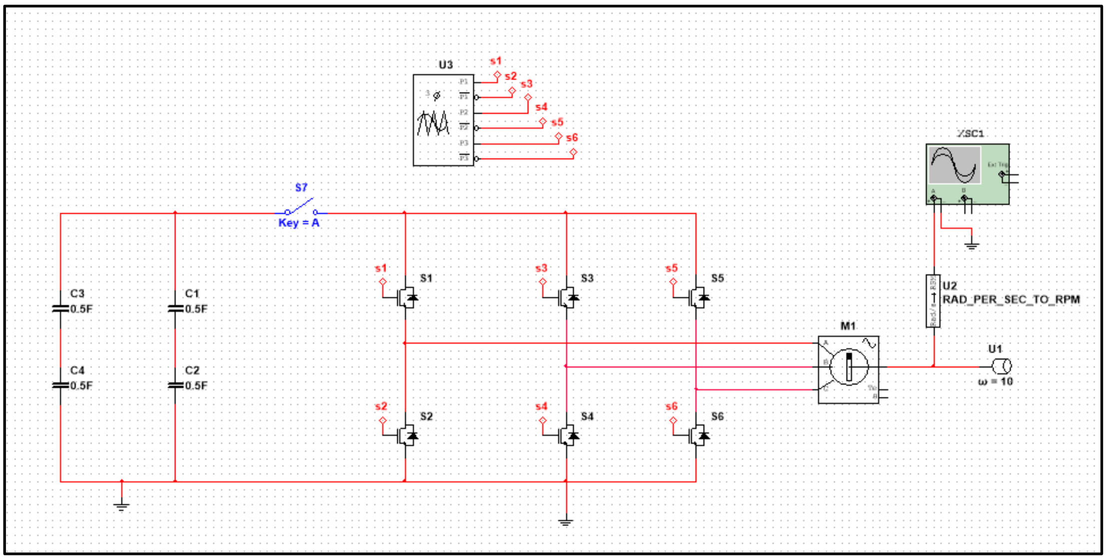


Figure 4 Inverter Circuit

During the regenerative process, the generated power is converted to DC supply using a power converter circuit and stored in the batteries, which is utilised to increase the range of the vehicle.

Since the braking event happens instantaneously and occurs for a short duration, and considering that the batteries have a limitation of charging, we cannot completely store re-generated power in the batteries within such a short span. Therefore additional auxiliary storage is required which is capable to charge at quicker rate. Also, frequent charging and discharging of the battery may lead to degradation of the battery reducing its life.

Proposed design for a practical regenerative braking system

To overcome the above limitation, the proposed design includes an ultra-capacitor bank connected parallel to the battery. Supercapacitors have a higher power density and cycling characteristics. This allows maximum energy to be recovered which is generated during regen. The supercapacitors enable the vehicle to accelerate and decelerate more efficiently with minimal loss of energy and minimal degradation of the battery pack. The system also includes a separate Buck and Boost converter connected across the ultracapacitor bank and the inverter circuit respectively.

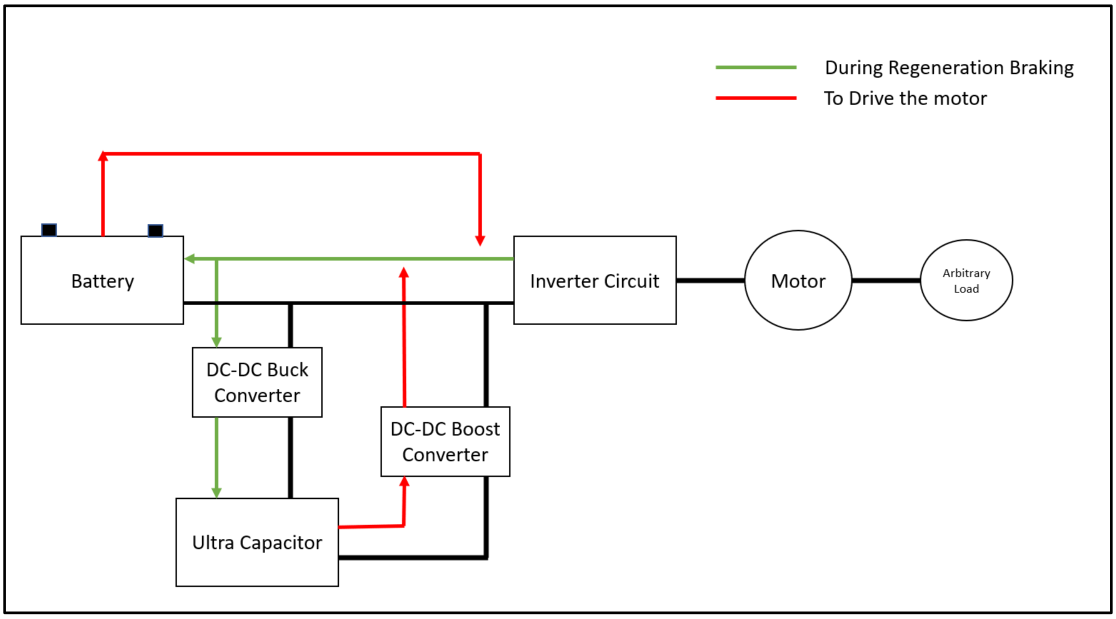


Figure 5 Block Diagram for Regenerative Braking

Analysis and discussion on the operation of the design

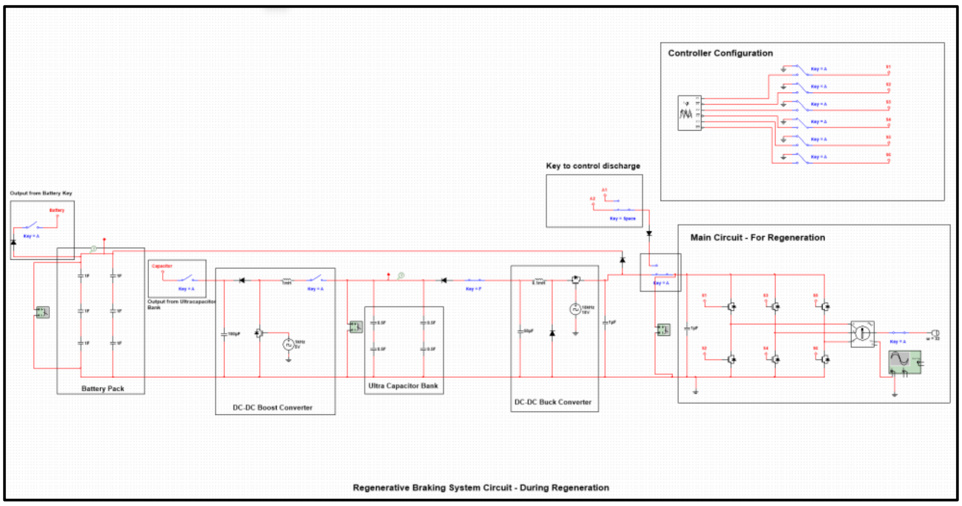


Figure 6 Proposed Circuit for Regenerative Braking

Case 1:- During the regeneration, the arbitrary load is connected to the motor, which behaves as a generator and the power generated is allowed to charge both battery and ultra-capacitor bank simultaneously. Since ultracapacitors have voltage limits and require relatively lower voltage for charging, a buck converter is being used to reduce the input voltage.

Case 2:- During acceleration, the load is disconnected from the motor allowing the motor to draw power from either source at a time. The power from the Ultra-capacitors is boosted using a Boost converter to discharge up to a threshold value which can be used to power the motor in demand of excess power.

The system circuit is designed in such a way that in event of failure of the ultracapacitor bank, the motor can still be powered using the battery.

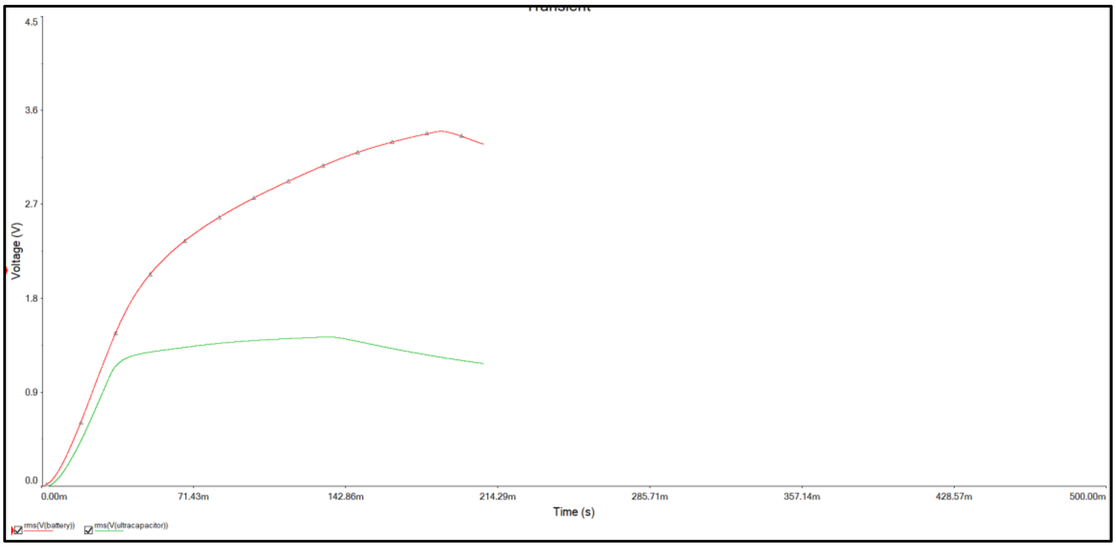


Figure 7 Charging and Discharging curves for the Battery and Ultra-capacitors during regenerative braking and driving mode

Part C- Practical limitations and suggested improvements

In Multisim the resistance across the wire is zero, therefore the length of the wire does not affect output results.

DC-AC Inverter Circuit

- Harmonic distortions in the circuit can be reduced by using filters to suppress the reverse transmittals.
- A suitable filter can be added between the inverter and load to obtain better output waveform.
- A Slight variation in output power at Phase A was observed in comparison to that of Phase B & C.

Regenerative Braking Circuit

- Since DC source could not be charged or discharged, multiple capacitors have been used to model the battery pack which makes it difficult to analyse the true effectiveness of the system.
- Using a separate Buck and Boost converter can result in efficiency drop but is a cheaper option and allows tuning as per the requirement of the situation.

- An unexpected low discharge was observed from the capacitor bank when the battery was used to power the motor.
- As a part of improvement a Buck-Boost converter can be used between the Battery and inverter circuit to regulate the voltage across.

Conclusion

In the report, the operation of both Inverter circuits and Regenerative systems employed in electric vehicles are summarized and demonstrated. The study also discussed points suggesting the limitations and improvements increase the efficiency of the system.

References

Bhurse, S. S. & Bhole, A. A., 2018. A review of Regenerative Braking in Electric Vehicles. *2018 INTERNATIONAL CONFERENCE ON COMPUTATION OF POWER, ENERGY, INFORMATION AND COMMUNICATION (ICCPEIC).*

Dixon, J. W. & Ortuzar, M. E., 2002. Ultracapacitors + DC-DC Converters in Regenerative Braking System. *IEE AESS System Magazine.*

Fan, Y., Zhang, M. & Li, J., 2020. Improvement of Power Factor and its Multisim Simulation. *Power, Intelligent Computing and Systems.*

Hughes, A. & Drury, B., 2019. In: *Electric Motors and Drives.* s.l.:Newnes.

Larminie, J. & Lowry, J., 2012. *Electric Vehicle Technology Explained.* Second ed. s.l.:Wiley.

Malode, S. K. & Adware, R. H., 2016. Regenerative Braking System in Electric Vehicles. *International Research Journal of Engineering and Technology IRJET.*